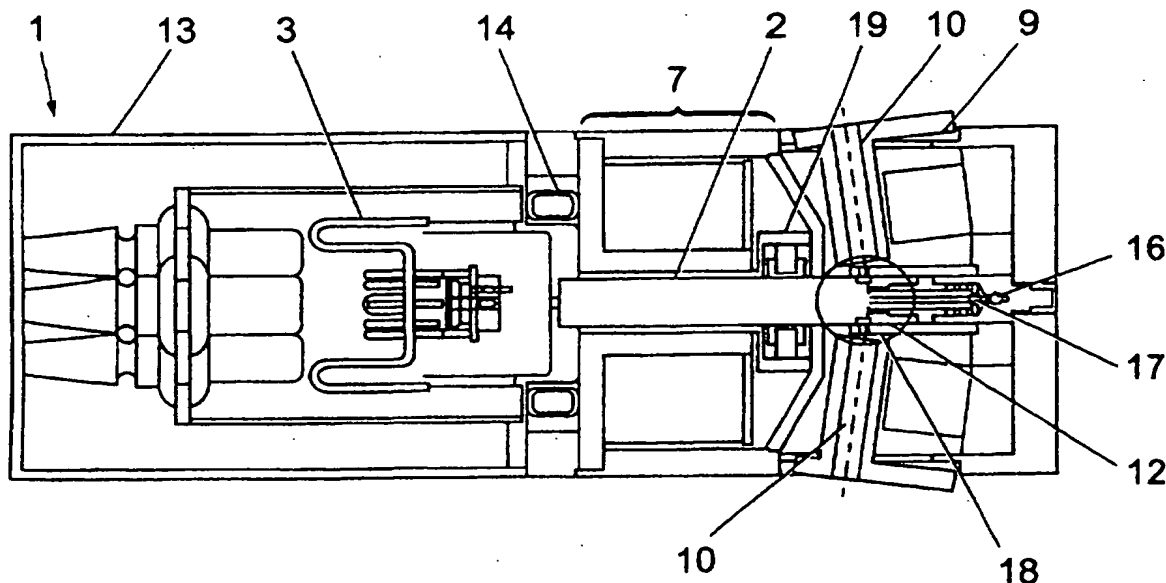


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(21) International Application Number: PCT/GB97/02580 (22) International Filing Date: 23 September 1997 (23.09.97) (30) Priority Data: 9620160.3 27 September 1996 (27.09.96) GB (71) Applicant (for all designated States except US): BEDE SCIENTIFIC INSTRUMENTS LIMITED [GB/GB]; Bowburn South Industrial Estate, Bowburn, Durham DH6 5AD (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): ARNDT, Ulrich, Wolfgang [GB/GB]; 28 Barrow Road, Cambridge CB2 2AS (GB). LONG, James, Victor, Percival [GB/GB]; University of Cambridge, Bullard Laboratory, Dept. of Earth Sciences, Madingley Rise, Cambridge CB3 0EZ (GB). DUNCUMB, Peter [GB/GB]; 5A Woollards Lane, Great Shelford, Cambridge CB2 5LZ (GB). (74) Agent: MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: X-RAY GENERATOR**(57) Abstract**

An X-ray generator comprises an evacuated and sealed X-ray tube, an electron gun, an X-ray target, an internal electron mask, and an X-ray window consisting of a thin tube of material with low X-ray absorption and high mechanical strength, for example beryllium. The window connects the tube to the target assembly containing the X-ray target. The generator preferably also includes a system for focusing and steering the electron beam onto the target, a cooling system to cool the target material, kinematic mounts to allow precise and repeatable mounting of X-ray devices for focusing the X-ray beam, and X-ray focusing devices of varying configurations and methods. The X-ray generator of the invention produces an X-ray source having a focal spot or line of very small dimensions and is capable of producing a high intensity X-ray beam at a relatively small point of application using a low operating power.

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1 X-Ray Generator

2

3 This invention relates to an X-ray generator and in
4 particular to an X-ray generator suitable to be closely
5 coupled to a focusing X-ray device.

6

7 X-ray generators comprise an electron gun, an X-ray
8 target and an X-ray exit window, generally in a sealed
9 vacuum. Prior art generators produce X-ray beams
10 having a relatively large focal spot or line. Many
11 applications require a precisely collimated X-ray beam.
12 To achieve this relatively small apertures are coupled
13 with the generator to restrict beam diameter and
14 divergence, but this results in a large loss of X-ray
15 intensity.

16

17 For many applications the most effective way of using
18 the X-rays emitted from the target of an X-ray tube is
19 to form an image of the source, i.e. of the electron
20 focus on the target, on the specimen. For
21 crystallographic applications, it is normally essential
22 that the convergence or divergence of the rays incident
23 on the sample be very small. To maximise the X-ray
24 intensity at the sample the angle of collection at the
25 source should be as large as possible. The combination

1 of these two requirements implies that the imaging
2 optics should magnify. The sample size determines the
3 maximum useful image size (see Fig. 3). Fig. 3 shows
4 that the ratio of the collecting angle α at the source
5 S to the beam convergence angle β at the image I is
6 equal to the magnification of the focusing collimator
7 or focusing mirror F. In single-crystal
8 diffractometry, for example, the specimen crystal is
9 frequently about 300 μm in diameter. The X-ray source
10 should, therefore, be much smaller than 300 μm .

11
12 Maximum power loading of the target, without damage to
13 its surface is greatest when the source is a line focus
14 at a small take-off angle to give a foreshortening of
15 about 10 times.

16
17 It is an object of the present invention to provide an
18 X-ray generator which produces an X-ray source having a
19 focal spot or line of very small dimensions. It is a
20 further object of the present invention to provide an
21 X-ray generator capable of producing a high intensity
22 X-ray beam at a relatively small point of application
23 using a low operating power.

24
25 According to a first aspect of the invention there is
26 provided an X-ray generator comprising an electron gun,
27 electron focusing means and a target, the electron
28 focusing means being arranged such that the X-ray
29 source on said target may be varied in size and/or
30 shape and/or position.

31
32 Preferably the X-ray source on said target may be
33 varied from a small diameter spot to a line of small
34 width.

35
36 Preferably the generator further comprises an X-ray

1 exit window comprising a tube of material with low X-
2 ray absorption and of a small diameter to allow close
3 coupling of X-ray focusing devices.
4

5 Preferably the electron focusing means comprises an
6 electron beam focusing means mounted around the X-ray
7 tube. The electron beam focusing means may comprise an
8 x-y deflection system for centring the electron beam in
9 the X-ray tube. The electron beam focusing means may
10 further comprise at least one electron lens, preferably
11 an axially symmetric or round lens, and at least one
12 quadrupole or multipole lens for focusing the electron
13 beam to a line focus. The line focus preferably has an
14 aspect ratio in the range 1:1 to 1:20.
15

16 The electron beam lenses may be magnetic or
17 electrostatic and are preferably electronically
18 controlled.
19

20 Preferably the material of the exit window has a high
21 mechanical strength and is preferably beryllium. The
22 exit window may form part of the mechanical structure
23 of the X-ray tube and preferably connects the X-ray
24 tube and the target.
25

26 Preferably the target is metal, most preferably a metal
27 selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co,
28 Fe, W, Au. In a preferred embodiment the target is
29 copper. The target surface may be orientated such that
30 the plane of the target surface is perpendicular or at
31 an angle to the axis of the X-ray tube.
32

33 The target may comprise a thin metal layer deposited on
34 a thicker substrate of a material with high thermal
35 conductivity. Preferably the substrate material is
36 diamond.

1 Preferably the generator further comprises a target
2 cooling means. According to a first embodiment the
3 cooling means may comprise means for directing a jet of
4 fluid onto the target, on the opposite side of the
5 target to the side on which the electron beam impinges.
6 The fluid is preferably air or water. According to a
7 second embodiment the cooling means may comprise means
8 for effecting heat transfer by conduction or convection
9 from the target.

10

11 Preferably the generator further comprises a deflection
12 means which spatially scans the position of the
13 electron beam over the face of the target.

14

15 Preferably the generator further comprises an electron
16 mask having an aperture adapted to align the focal spot
17 of the electron beam.

18

19 According to a second aspect of the invention there is
20 provided an X-ray generator comprising an electron gun,
21 an X-ray tube, a target and an X-ray exit window
22 comprising a tube of material with low X-ray absorption
23 and of small diameter to allow close coupling of X-ray
24 focusing devices.

25

26 According to a third aspect of the invention the
27 generator according to the first or second aspects is
28 coupled with an X-ray focusing means. The X-ray
29 focusing means preferably comprises a mirror.

30

31 The X-ray source according to the invention is designed
32 specifically to be closely coupled to focusing X-ray
33 devices. It is able to produce a focal spot or line of
34 very small dimensions, and thus maximise the benefit of
35 the focusing methods.

36

1 The distance from the electron focus to the exit window
2 exterior is very small, and can be as low as 7 mm or
3 less for a reflection target, or less than 1 mm for a
4 foil transmission target.

5

6 The X-ray generator according to the invention is
7 compact and provides a sealed tube.

8

9 The X-ray generator according to the invention needs
10 only low power because of the efficiency of the
11 collection and subsequent delivery of X-rays to the
12 sample.

13

14 The generator achieves a high brilliance, defined as X-
15 ray power per unit area per steradian.

16

17 An embodiment of the invention will now be described,
18 by way of example only, with reference to the
19 accompanying figures, where:

20

21 Fig. 1 shows a longitudinal section through an X-ray
22 generator according to the invention;

23

24 Fig. 2 shows a detail to an enlarged scale of part of
25 the X-ray generator shown in Fig. 1;

26

27 Fig. 3 shows the relationship between the size of an X-
28 ray source and the image at a sample; and

29

30 Fig. 4 shows the variation in X-ray intensity as an
31 electron beam is scanned across an aperture in front of
32 a target.

33

34 With reference to Figs. 1 and 2, the X-ray generator 1
35 comprises an evacuated and sealed X-ray tube 2,
36 containing the following elements:

- 1 - Electron gun 3
- 2 - X-ray target 4
- 3 - Internal electron mask 5
- 4 - X-ray window 6 consisting of a thin tube of
- 5 material with low X-ray absorption and high
- 6 mechanical strength, for example beryllium.
- 7 This window also connects the tube 2 to the
- 8 target assembly 12 containing the target 4.

9

10 The tube 2 is contained within a housing 13. The

11 generator 1 also includes a system 7 for focusing and

12 steering the electron beam onto the target, a cooling

13 system 8 to cool the target material, kinematic mounts

14 9 to allow precise and repeatable mounting of X-ray

15 devices for focusing the X-ray beam, and X-ray focusing

16 devices 10 of varying configurations and methods. X-

17 ray mirrors 10 are supplied in pre-aligned units so

18 that re-alignment is not necessary after exchange.

19

20 The X-ray tube 2 produces a well focused beam of

21 electrons impinging on a target material 4. The

22 electron beam may be focused into a spot or a line, and

23 the dimensions of the spot and line as well as its

24 position may be changed electronically. A spot focus

25 having a diameter falling in the range 1 to 100 μm ,

26 generally 5 μm or larger, may be achieved.

27 Alternatively a line focus may be achieved whose width

28 falls in a similar range, having a length to width

29 ratio of up to 20:1.

30

31 An electron beam mask of 5 of metal (eg tungsten) in

32 the form of an internal electron beam aperture 11, with

33 suitable dimensions, for example a rectangular slot for

34 the line focus, may be used with suitable feedback and

35 control mechanisms to automatically align the focal

36 spot and to maintain its position on the target, for

1 example by scanning the electron beam over the aperture
2 11 and measuring the emerging X-ray intensity.

3

4 The electron beam is produced by an electron gun 3,
5 consisting of a Wehnelt electrode and cathode. The
6 cathode may be either:

- 7 - a filament of tungsten or alloy, for example
8 tungsten-rhenium, having either a hairpin or a
9 staple shape; or
- 10 - an indirectly heated activated dispenser cathode,
11 which may be flat or of other geometry, for
12 example a rod with a domed end.

13 The dispenser cathode has the advantage of extended
14 lifetime and increased mechanical strength. With a
15 flat surface the dispenser cathode has the further
16 advantage of requiring only an approximate degree of
17 alignment in the Wehnelt electrode.

18

19 Primary focus is achieved by an anode at a suitable
20 distance from the electron gun.

21

22 A thin tube of material with low X-ray absorption but
23 high mechanical strength and stability, such as
24 beryllium, is used to form the exit window 6 for the
25 emerging X-rays. The tube must exhibit good vacuum
26 seal characteristics. This tube also forms the
27 mechanical connection between the X-ray tube 2 and the
28 target assembly 12. Such an arrangement saves space
29 and complexity in the formation of X-ray windows.

30

31 The electron beam from the gun is centred in the X-ray
32 tube 2 by a centring coil 14 or set of quadrupole
33 lenses. Alternatively it may be centred by multipole
34 lenses. The electron beam is focused to a spot of
35 varying diameter. Focusing down to a diameter of less
36 than 5 μm or better may be achieved by an axial lens 7

1 consisting of either quadrupole, multipole or solenoid
2 type.

3

4 The spot focus may be changed to a line focus with a
5 further set of quadrupole or multipole lenses. Lines
6 with an aspect ratio of greater than 10:1 are possible.
7 A line focus spreads the load on the target. When
8 viewed at a suitable angle, the line appears as a spot.

9

10 Lenses are preferably magnetic, but may be
11 electrostatic. All the lenses are electronically
12 controlled, enabling automatic and continuous alignment
13 and scanning of the focal spot. Change from spot to
14 line is also automatic, as is the change of beam
15 diameter.

16

17 The target 4 is a metal, for example Cu, but it can be
18 another material depending on the wavelength of the
19 characteristic radiation required, for example Ag, Mo,
20 Al, Ti, Rh, Cr, Co, Fe, W or Au. The target 4 is
21 either perpendicular to the impinging electron beam, or
22 may be inclined to decrease the absorption of the
23 emitted X-rays.

24

25 The target is cooled either by:

- 26 - a jet of cooling fluid (water, air or another
27 fluid) directed onto the rear surface of the
28 target area by cooling nozzle 15; or
- 29 - conducted or convected heat transfer from the rear
30 of the target 4.

31

32 The cooling fluid is circulated through an inlet 16 and
33 outlet 17.

34

35 An increase in cooling efficiency (and hence an
36 increase in the permissible target loading) may be

1 achieved by the use of a thin metal film of target
2 material deposited on a thick substrate made from a
3 material with a high thermal conductivity (eg diamond).
4 The target could comprise a thin solid of a single
5 material or it could be laminated with a different
6 material of high thermal conductivity. These targets
7 may be used with different cooling geometries, for
8 example those employing high or low water pressure or
9 forced or natural convection.

10
11 Both foil transmission and reflection targets may be
12 used as a target 4.

13
14 Integrated mechanical shutters 18 are positioned
15 between the window 6 and the X-ray focusing elements
16 10, to block the emerging X-ray beam.

17
18 The placement of the shutter 18 before the focusing
19 elements 10 protects the surface of the mirror from
20 extended radiation damage.

21
22 A compact X-ray detector may be included to monitor and
23 continuously optimise the position of the electron
24 focal spot. This may be a small solid state detector
25 or other X-ray detecting device.

26
27 The system encompasses an X-ray focusing device 10
28 located close to the source to provide a magnified
29 image of the focal spot at controlled varying distances
30 from the source. Options for the X-ray focusing
31 systems are:

32 1 Micromirrors: use specular reflectivity from a
33 gold or similar coating of highly controlled
34 smoothness (around 10 Å rms), from a circularly
35 symmetric profile.

36 - Ellipsoidal profile: gives focused beam of X-

- 1 rays (currently 300 μ m diameter 600 mm from
2 focal spot). Measured insertion gain of >
3 150 (could be 250+). Reason for close
4 coupling is so that a large solid angle of
5 radiation may be collected, but also focusing
6 element forms a magnified image of the focal
7 spot at the sample (low beam divergence but
8 high insertion gain)
9 - Paraboloidal profile: gives a nearly parallel
10 beam (expected gains around 200+)
11
12 2 Kirkpatrick-Baez type:
13 - Bent plates arranged in combinations of
14 elliptical or parabolic or combination
15 - Allows simple change of mirror profiles to
16 suit different applications
17
18 3 Other possibilities:
19 - Zone plates
20 - Bragg Fresnel optics
21 - Multilayer optics
22

23 The distance x between the focusing mirror 10 and the
24 source on the target 4 is small, usually less than 20
25 mm, preferably about 11 mm, to ensure close coupling.
26

27 Example

28
29 A number of copper-target X-ray tubes with focusing
30 collimators were constructed to the same basic
31 specifications shown in the table below.
32

33 Table of Specifications

34
35 X-ray tube target Copper, cooled by water or
36 forced air

11

1	Source size	15 μm x 150 μm viewed at 6°
2		
3	Present tube current	0.2 mA at 30 kV
4		
5	X-ray focusing	Ellipsoidal mirror, gold
6		surface
7		
8	Source-to-mirror	11 mm
9	distance	
10		
11	Solid angle of	8.0 x 10 ⁻⁴ sterad
12	collection	
13		
14	Beam convergence	10 ⁻³ rad
15	at sample	
16		

17 The cathode is at negative high voltage and the
18 electron gun consists of a filament just inside the
19 aperture of a Wehnelt grid which is biased negatively
20 with respect to the filament. The electrons are
21 accelerated towards the anode which is at ground
22 potential and pass through a hole in the latter and
23 then through a long pipe (tube 2) towards the copper
24 target 4. An electron cross-over is formed between the
25 Wehnelt and anode apertures and this is imaged on the
26 target by the iron-cored axial solenoid 7 which
27 surrounds the vacuum pipe. The best electron focus is
28 obtained when the beam passes very accurately along the
29 axis of the solenoid. Two sets of beam deflection
30 coils 14, which may be iron-cored, are employed in two
31 planes separated by 30 mm, mounted between the anode of
32 the electron gun 3 and the axial solenoid 7 to centre
33 the beam. Between the solenoid 7 and the target 4 is
34 an air-cored quadrupole magnet which acts as a
35 stigmator 19 in that it turns the circular cross-
36 section of the beam into an elongated one. This

1 quadrupole 19 can be rotated about the tube axis so as
2 to adjust the orientation of the line focus. The beam
3 can be moved about on the target surface 4 by
4 controlling the currents in the four coils of the
5 quadrupole 19.

6
7 For a tube power below 2 watts the foil target is
8 adequately cooled by radiation alone, but at higher
9 powers forced-air or water-cooling is necessary. The
10 tube may be operated continuously at 6 watts but the
11 maximum power compatible with low damage to the target
12 surface 4 is still to be established.

13
14 Computer simulations show that the loading limit of a
15 water-cooled copper target and a focus of $15\ \mu\text{m} \times 300$
16 μm is about 20 watts. Experiments suggest that this
17 figure can be somewhat improved upon by increasing the
18 turbulence in the flow of the coolant. Another
19 approach is to sandwich a layer of a material with a
20 very high thermal conductivity between a very thin
21 copper target layer and a cooled copper block. The
22 sandwiched layer may be a Type II diamond layer, and
23 may be sandwiched between a $5\ \mu\text{m}$ thick copper target
24 layer and a water-cooled copper block. Diamond has a
25 thermal conductivity which is up to four times that of
26 copper and our calculations show that its use should
27 allow the permissible power dissipation to be
28 approximately doubled.

29
30 The electron source of a micro-focus X-ray tube must
31 have a high brightness to produce gun currents of the
32 order of 1 mA.

33
34 An indirectly heated cathode a Few hundred micrometers
35 in diameter may be used. The beam cross-section
36 remains circular until the beam reaches the stigmator

1 quadrupole while it can be drawn out into a line
2 between 10 μm and 30 μm in width and with a length-to-
3 width ratio up to 20:1. Such an electron source
4 consumes a much lower filament power than the hair-pin
5 tungsten filaments customary for low-power
6 applications; since it operates at a lower temperature,
7 it can have a life of several thousand hours.

8
9 The tube is run in a saturated condition in which the
10 current is virtually independent of the filament
11 temperature but is determined by the bias voltage
12 between filament and Wehnelt electrode. This bias
13 voltage is the potential drop produced by the tube
14 current flowing through a high resistor; this form of
15 autobias produces a very stable tube current which is
16 readily controlled by varying the bias resistance.

17
18 The electron-optical performance of the tubes has been
19 investigated by fitting some of them with 20 μm thick
20 transmission targets. This allowed pinhole photographs
21 of the focus to be made. A quick way of assessing the
22 focus was to view the magnified shadow cast by a 200-
23 or 400-mesh grid. The electron beam could also be
24 scanned across a rectangular aperture immediately in
25 front to the target. The results are shown in Fig. 4,
26 which shows how the X-ray intensity varies as the
27 electron beam is scanned across the aperture in front
28 of the target. It can be seen that the intensity
29 reaches a peak of about 4000 cps over a range of
30 distance between 60 and 220 micrometres.

31
32 The insertion gain of ellipsoidal mirrors was measured.
33 This gain was defined as the ratio of $\text{CuK}\alpha$ X-ray flux
34 into the 0.3 mm diameter image of the X-ray source
35 formed at a distance of 600 mm from the source to the
36 flux into the same area without the mirror. Under

1 these conditions the cross-fire at the sample position
2 is about 1 milliradian. For the best mirrors the
3 insertion gain was 110.

4
5 The X-ray intensity obtained as above was also compared
6 with that obtained at the focus of a standard double
7 Franks mirror arrangement used with an Elliot GX-21
8 rotating anode X-ray generator operated at 2kW. (This
9 is a conventional combination of X-ray tube and
10 collimator for protein crystallography). When the tube
11 according to the invention was operated at below 1
12 watt, the intensity was only 25 times less than that
13 from the rotating-anode operated at a power 2000 times
14 greater. Further improvements are possible, both in X-
15 ray tube power and in mirror performance. It should be
16 noted that the insertion gain calculated simply on the
17 basis of solid angles of the cone of radiation
18 collected from the source and on the highest values of
19 X-ray reflectivity which have been measured is
20 approximately five times greater than that achieved so
21 far.

22
23 These and other modifications and improvements can be
24 incorporated without departing from the scope of the
25 invention.

1 CLAIMS

2

3 1. X-ray generator comprising an electron gun, an X-
4 ray tube, electron focusing means and a target
5 adapted to have an X-ray source formed thereon,
6 the electron focusing means being arranged such
7 that the X-ray source on the target may be varied
8 in size and/or shape and/or position.

9

10 2. X-ray generator according to Claim 1, wherein the
11 X-ray source on said target may be varied from a
12 small diameter spot to a line of small width.

13

14 3. X-ray generator according to Claim 1 or 2, further
15 comprising an X-ray exit window comprising a tube
16 of material with low X-ray absorption and of a
17 small diameter to allow close coupling of X-ray,
18 focusing devices.

19

20 4. X-ray generator according to Claim 3, wherein the
21 material of the exit window has a high mechanical
22 strength and is preferably beryllium.

23

24 5. X-ray generator according to Claim 3 or 4, wherein
25 the exit window connects the X-ray tube and the
26 target.

27

28 6. X-ray generator according to any preceding Claim,
29 wherein the electron focusing means comprises an
30 x-y deflection system for centring the electron
31 beam in the X-ray tube.

32

33 7. X-ray generator according to Claim 6, wherein the
34 electron beam focusing means further comprises at
35 least one electron lens, preferably an axially
36 symmetric or round lens, and at least one

1 quadrupole or multipole lens for focusing the
2 electron beam to a line focus.

3

4 8. X-ray generator according to any preceding Claim,
5 wherein the target is a metal foil transmission
6 target, the metal being selected from the group
7 Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, and Au.

8

9 9. X-ray generator according to any preceding Claim,
10 wherein the surface of the target impinged upon by
11 the electron beam is orientated such that the
12 plane of the target surface is perpendicular or at
13 an angle to the axis of the X-ray tube.

14

15 10. X-ray generator according to any preceding Claim,
16 wherein the target comprises a thin metal layer
17 deposited on a thicker substrate of a material
18 with high thermal conductivity, preferably
19 diamond.

20

21 11. X-ray generator according to any preceding Claim,
22 wherein the generator further comprises a target
23 cooling means.

24

25 12. X-ray generator according to any preceding Claim,
26 further comprising an electron mask having an
27 aperture adapted to align the focal spot of the
28 electron beam.

29

30 13. X-ray generator comprising an electron gun, an X-
31 ray tube, a target and an X-ray exit window
32 comprising a tube of material with low X-ray
33 absorption and of small diameter to allow close
34 coupling of X-ray focusing devices.

35

36 14. X-ray generator according to any preceding Claim,

1 further comprising an X-ray focusing means coupled
2 closely to said target.

3

4 15. X-ray generator according to Claim 14, wherein the
5 X-ray focusing means comprises an X-ray mirror
6 whose longitudinal alignment axis is arranged at
7 an angle to the axis of the X-ray tube.

8

9 16. X-ray generator according to Claim 15, wherein the
10 angle is between 80° and 90° , preferably about
11 84° .

12

1 / 2

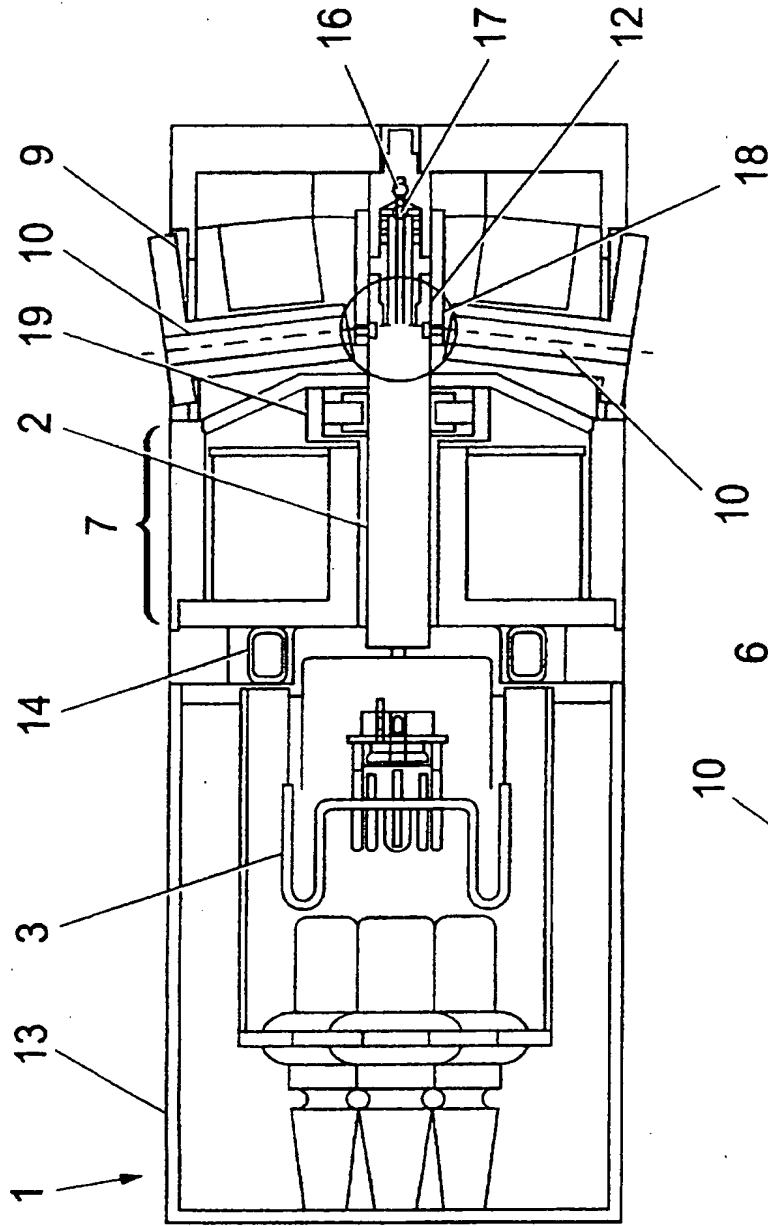


Fig. 1

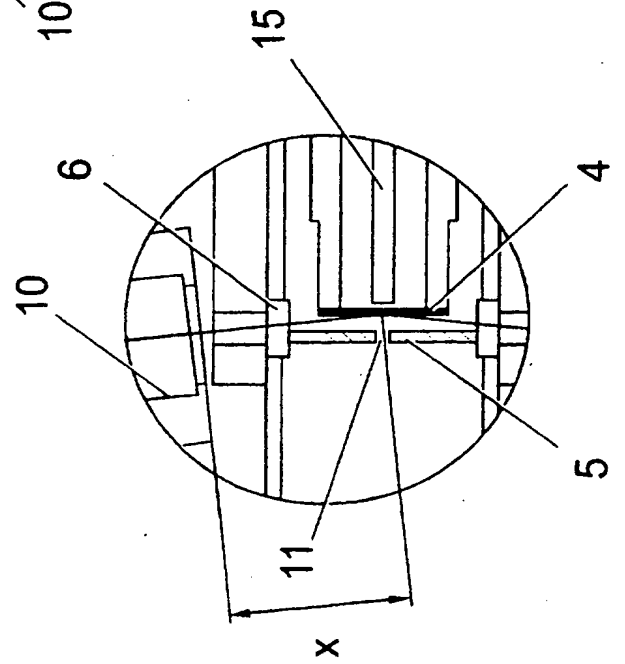


Fig. 2

2 / 2

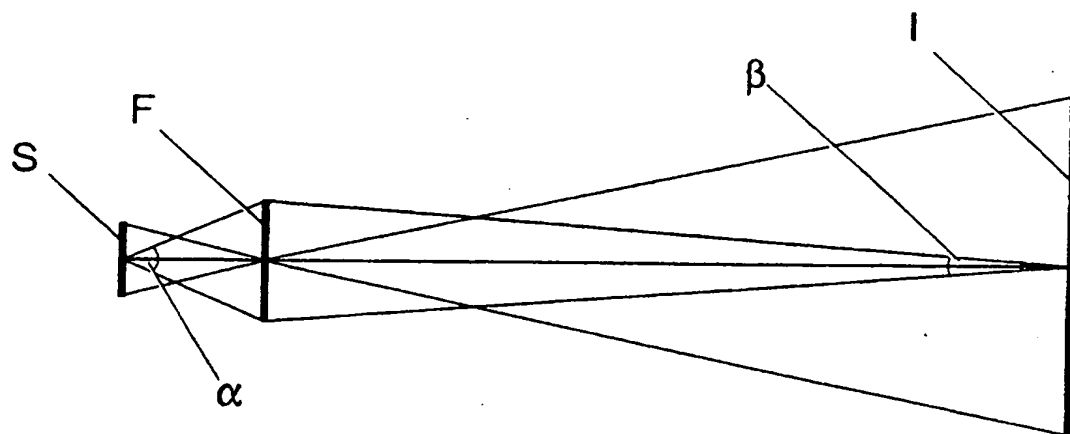


Fig. 3

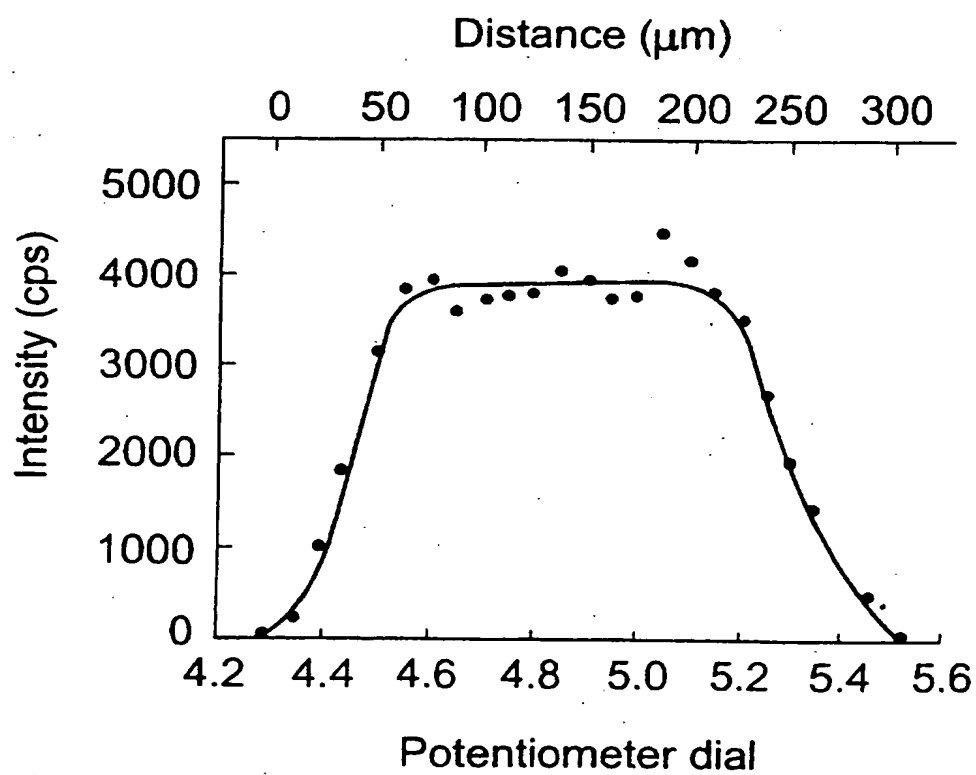


Fig. 4

INTERNATIONAL SEARCH REPORT

In. Application No
PCT/GB 97/02580

A. CLASSIFICATION OF SUBJECT MATTER IPC 6 H01J35/14		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC 6 H01J		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document with indication, where appropriate, of the relevant passages	Relevant to claim No
X	US 3 732 426 A (SHIMIZU T) 8 May 1973 see figures see column 1, line 50 - column 2, line 43	1-5, 9, 13
Y	---	6-8, 10, 11, 14-16
Y	US 4 827 494 A (KOENIGSBERG WILLIAM D) 2 May 1989 see figure 1 see column 3, line 39 - line 55	6, 7
Y	EP 0 319 912 A (WANG CHIA GEE DR) 14 June 1989 see column 5, line 25 - line 38 see column 6, line 19 - line 33 ---	8, 10
	--- -/--	
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C <input checked="" type="checkbox"/> Patent family members are listed in annex		
Special categories of cited documents "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
Date of the actual completion of the international search 5 January 1998		Date of mailing of the international search report 13/01/1998
Name and mailing address of the ISA European Patent Office P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040 Tx. 31 651 epo nl. Fax: (+31-70) 340-3016		Authorized officer Colvin, G

INTERNATIONAL SEARCH REPORT

In. National Application No

PCT/GB 97/02580

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PATENT ABSTRACTS OF JAPAN vol. 016, no. 215 (E-1204), 20 May 1992 & JP 04 036943 A (TOSHIBA CORP), 6 February 1992, see abstract ---	11, 14-16
X	GB 1 444 109 A (JEOL LTD) 28 July 1976 see figure 1 see page 3, line 65 - line 73 -----	1

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